TESTS OF BRAKE SHOES

BY

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THESIS

FOR THE

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Albert Frederick Stuebing

ENTITLED Tests of Brake Shoes.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF B.S. in Railway Mechanical Engineering.

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TESTS OF BRAKE SHOES.

The more general application of steel in the construction of passenger coaches has resulted, in the past few years, in a very great increase in the weight of first-class passenger equipment and with the advent of the all-steel car the weight on each wheel has become so great that considerable difficulty is met with in providing adequate braking facilities for making quick stops from the high speeds now common in passenger service.

While many of the problems which had to be met in designing braking equipment for these heavy cars were solved by the tests conducted on the Lake Shore and Michigan Southern Railroad in the fall of 1909, no satisfactory data concerning the coefficient of friction at the high brake shoe pressures used in these tests was obtained and the committee merely recommended that the efficiency of the braking apparatus multiplied by the coefficient of friction be assumed to be 7.5 per cent in any calculations of brake cylinder sizes of other details of equipment where the recommended maximum pressure of 18000 pounds on the shoe is used.

While the committee made the recommendation that the pressure on each brake shoe should not exceed 18000 pounds, higher pressures were used in the tests without excessive wear and with no signs of breaking down on the part of the brake shoes, and with the modern air brake equipments known as the "L.N." and "P.C." the pressure obtained in emergency applications on heavy cars will in many cases exceed 20,000 pounds.

For instance, the standard all-steel Pullman sleeping car has a weight of 142,000 pounds or 11,833 pounds per wheel. If braked at 90 per cent on 60 pounds cylinder pressure the shoe pressure will be as follows:

In full service application (50 lbs. brake cylinder pressure), 8875 lbs.

In emergency with "L.N." equipment(100 lbs. brake cylinder pressure), 17750 lbs.

In emergency with "P.C." equipment (180 per cent braking power), 21300 lbs.

Or taking the extreme case of the eight wheel steel coach of the Pennsylvania Railroad, which has a total weight of 119,000 pounds and a weight per wheel of 14,880 pounds, we find the pressure as follows:

At 90 per cent on 60 lbs. brake cylinder pressure,

Shoe pressure in full service application,	11,160 lbs.
In emergency with "L.N." equipment,	22,310 lbs.
In emergency with "P.C." equipment,	26,770 lbs.

It was with a view to determining the behavior of brake shoes under the severe conditions of stops from high speed with heavy pressures that the experiments described in the following pages were undertaken.

Brake Shoe Testing Machine.

The tests were conducted upon the brake shoe testing machine of the University of Illinois which is built in accordance with the specifications of the Master Car Builders Association and has a wheel the energy of which is equivalent to a load of 12,500 pounds on the wheel. The kinetic energy of the fly wheel in terms of the velocity at the rim of a 33 inch wheel is espressed by the equation:

$$K.E. = 412\ S^2,$$

in which K.E. is the kinetic energy of the fly wheel in foot-pounds and S is the velocity at the rim of the car wheel in miles per hour.

If we compare this with the kinetic energy of translation per wheel of an all-steel Pullman car (weight, 142,000 pounds), we find that they are very nearly the same. The weight per wheel of this car is 11833 pounds.

$$\begin{aligned} K.E. &= \frac{1}{2} MV^2 \\ &= \frac{11,833}{2 \cdot 32.2} V^2 \\ &= 183.75\ V^2 \end{aligned}$$

$$V = 1.466\ S \qquad V^2 = 2.148\ S^2$$

$$K.E. = 395.4\ S^2$$

K.E. = kinetic energy in ft.-lbs.

$M = \frac{G}{g} = Wt. \div 32.2$

V = velocity in ft. per sec.

S = velocity in miles per hour.

In this calculation the kinetic energy of rotation of the wheels has been neglected as no account is taken of it in the formula for kinetic energy of the fly wheel of the brake shoe machine.

The close correspondence between the kinetic energy of the fly wheel and the kinetic energy dissipated per wheel in actual service stops from the same speed makes it reasonable to suppose that the coefficients obtained from the testing machine will not vary greatly from those obtained in service due to the difference in energy dissipated which as will be shown later affects the coefficient of friction materially.

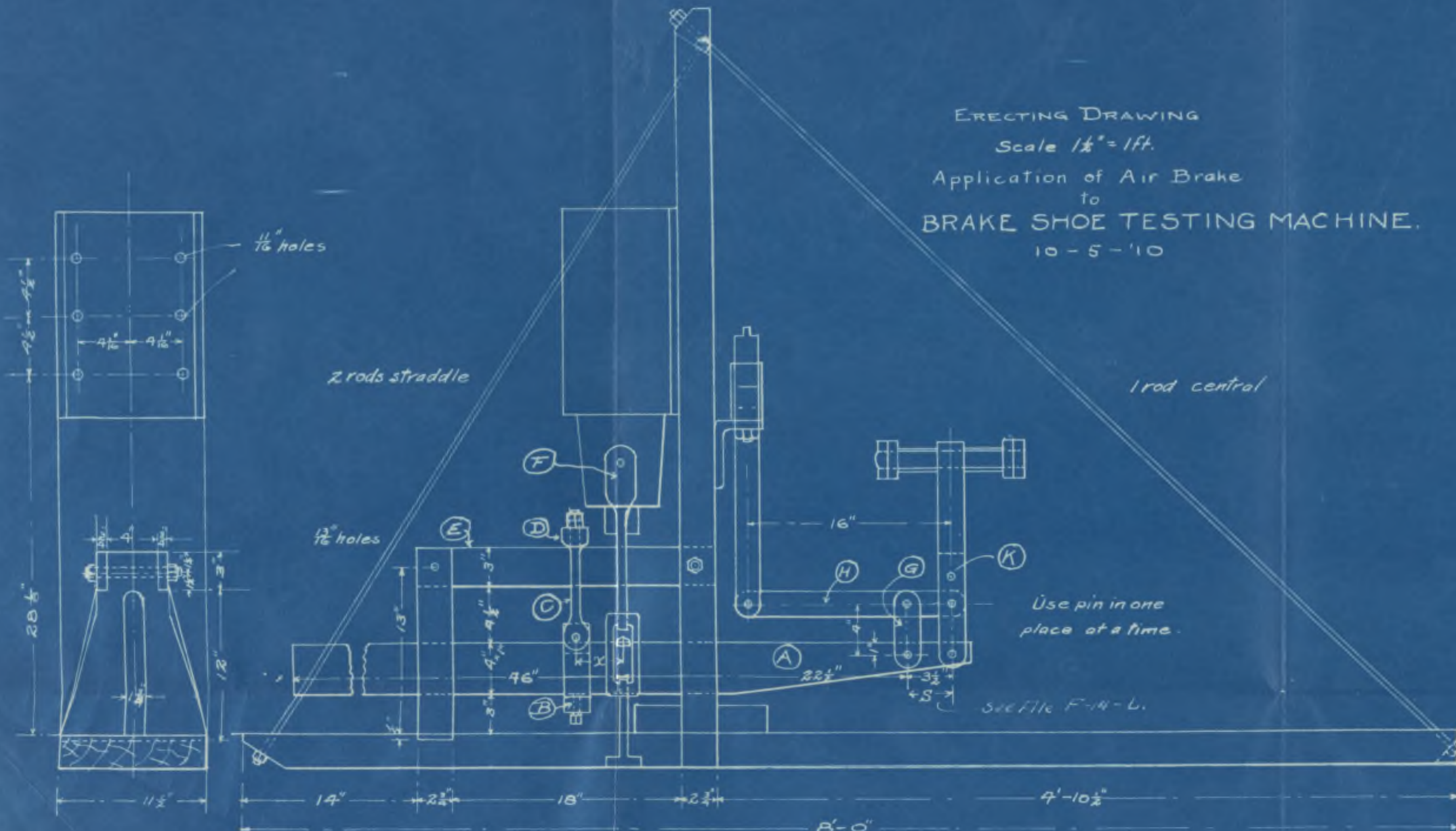
Method of Making Tests.

In making the tests two methods were used: first, applying pressure by means of weights, and second, applying pressure by means of compressed air operating a brake cylinder.

The tests which were made by means of weights were conducted in the usual manner. Weights sufficient to give the desired pressure at the shoe were placed on the weight lever and raised so that the weight was borne by the trip and the shoe was not in contact with the wheel. The wheel was then brought to a speed slightly higher than that at which the application was to be made and the clutch connecting the wheel with the engine was thrown out. The paper travel and the seconds clock were then started and when the speed of the wheel had decreased to the point desired the weights were allowed to drop.

When the wheel had come to rest the weights were again raised and the dynamometer was jarred until the pen arm returned to its zero position. A line was then drawn to give the zero reading of the dynamometer.

To enable applications to be made by means of compressed air the attachment shown in the blue print (Fig.I.) was used. The push rod of the brake cylinder was arranged to bear upon a


ERECTING DRAWING
Scale 1½" = 1 ft.
Application of Air Brake
to
BRAKE SHOE TESTING MACHINE.
10 - 5 - '10
11/16" holes
2 rods straddle
1 rod central
13/16" holes
Use pin in one
place at a time.
See File F-14-L.
16"
22½"
46"
3½"
5
28⅛"
12"
11½"
14"
2¾"
18"
2¾"
4'-10½"
8'-0"
A
B
C
D
E
F
G
H
K

C146

knife edge on the lever, A, which was supported at one end by the rod, C, which served as a movable fulcrum. The other end was attached to the weighing lever, H, by two links shown at G. One end of the weighing lever was connected by the rod, K, to the weight lever of the brake shoe machine while the other end was supported by a piston working in an oil cylinder from which a pipe connection led to an indicator mounted above the paper drum with the pencil in line with the recording mechanism of the dynamometer.

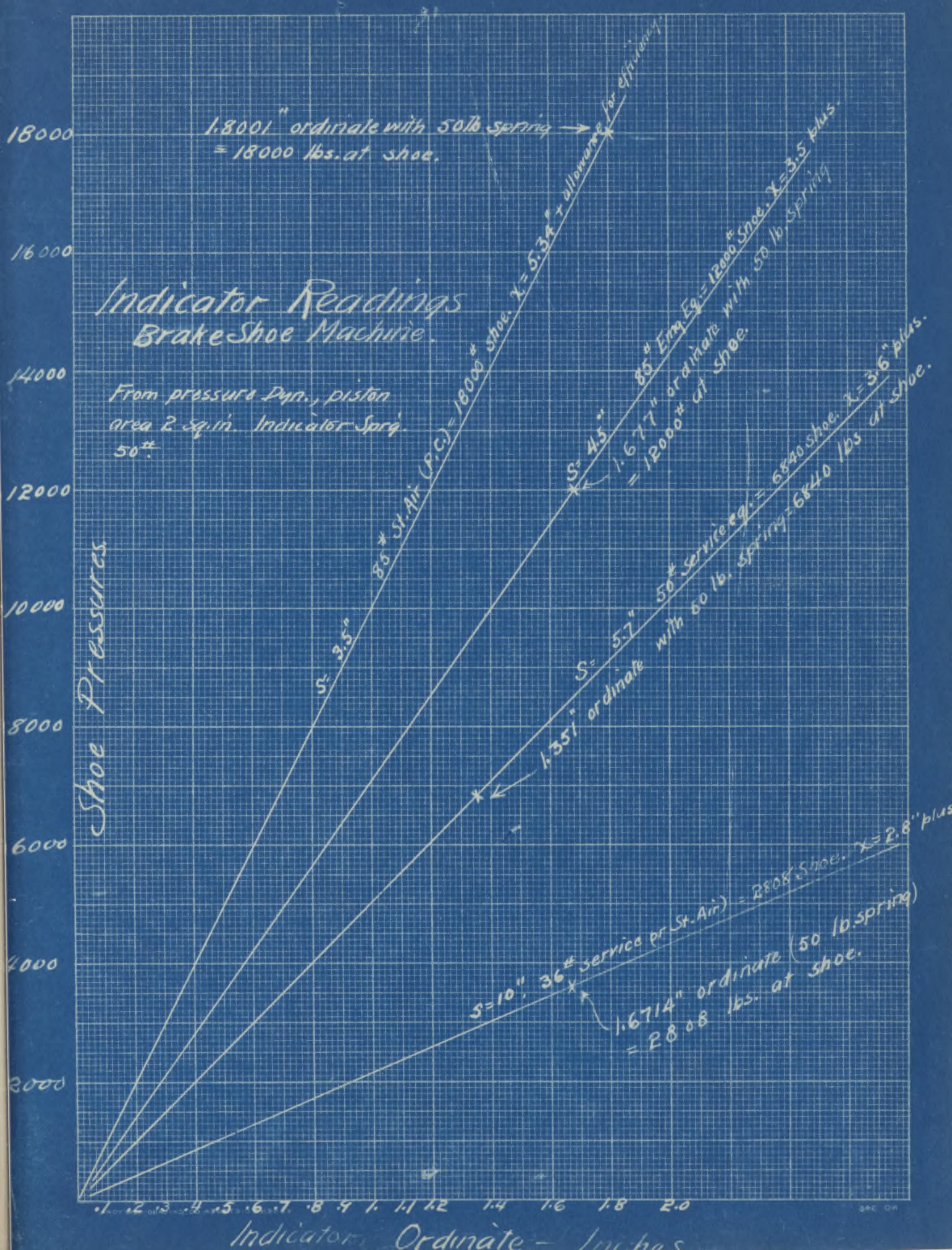
By this method a curve of instantaneous pressures was obtained which was free from errors occasioned by the friction of the packing leather or tension of the release spring.

The shoe pressures corresponding to various ordinates and with various settings of the fulcrum of lever A may be found from the curves in Fig. 2.

In making tests with air instead of weights the automatic application was not used since the shoe pressure could not be controlled with sufficient accuracy. The method used in these tests was as follows: The auxiliary reservoir was charged to the pressure which had been found by trial to equalize with the brake cylinder at the desired pressure. The connection with the brake pipe was then closed and when all was in readiness the application was made by opening a valve giving direct connection between the brake cylinder and the auxialiary reservoir.

To prevent the escape of air owing to the higher pressure in the brake pipe when the application was made the exhaust from the triple valve was closed during applications.

After each application, both with air and weights, the


1.8001" ordinate with 50lb spring
= 18000 lbs. at shoe.
Indicator Readings
Brake Shoe Machine.
From pressure Dyn., piston
area 2 sq. in. Indicator Sprg.
50#.
85# St. Air (P.C.) = 18000# shoe. X = 5.34" + allowance for efficiency
S= 3.5"
85# Emg. Eq. = 12000# Shoe. X = 3.5 plus.
S= 4.5"
1.677" ordinate with 50 lb. spring
= 12000# at shoe.
50# Service eq. = 6840 shoe. X = 3.6" plus.
S= 5.7"
1.351" ordinate with 50 lb. spring = 6840 lbs at shoe.
S=10". 36# service pr. St. Air) = 2808 Shoes. X = 2.8" plus
1.6714" ordinate (50 lb. spring)
= 2808 lbs. at shoe.
18000
16000
14000
12000
10000
8000
6000
4000
2000
Shoe Pressures.
.1 .2 .3 .4 .5 .6 .7 .8 .9 1. 1.1 1.2 1.4 1.6 1.8 2.0
Indicator Ordinate — Inches

wheel was dressed by holding a piece of carborundum against it while it was revolving until the scale left on the wheel by the shoe had been removed.

The shoes in every case were cooled between applications so that at the start they were always approximately at the temperature of the room in which the tests were conducted.

Brake Shoe Machine Cards.

The card obtained from the testing machine when the application is made with weights has two lines, one drawn by the arm of the dynamometer and showing the tangential pull at the shoe to a scale of 1 inch per 1000 pounds pull, the other having offsets at intervals of one second from which the speed is obtained. The gearing of the drum by which the paper is driven is such that one inch of paper travel corresponds to 65.06 feet of car travel.

A check upon the paper travel is given by the revolution counter which is geared to make 70 revolutions for every 69 revolutions of the wheel. Thus every revolution of the counter corresponds to 8.6934 feet of car travel.

While the length of the card was always checked by comparison with the readings of the revolution counter the length of stop was in every case taken from the card since it was found that the paper did not slip any measurable amount. By this method an error in the length of stop did not produce a corresponding error in the coefficients of friction.

The cards obtained where the application was made by means of air differed from those taken with weights only in having a third line which recorded the pressure obtained on the shoe. In all the tests the setting was such that the scale of the ordinate was 1 inch = 10,000 pounds shoe pressure.

Tests.

Three different makes of shoes were used in the experiments, a plain cast iron shoe with a steel back, the so-called Diamond-S shoe, made of very hard iron with inserts of soft steel in the form of expanded metal, and the Streeter shoe which is of cast iron with white iron inserts in the face of the shoe. At the outset it was planned to make tests with a cast iron shoe with chilled ends but breakage was so frequent that the tests were abandoned.

Results of Tests.

Cast Iron Shoe.

The cast iron shoe was tested at pressures varying by 2000 pound increments from 12000 to 24000 pounds. While the changes in the action on the shoe were progressive and noticeable throughout the entire range, the performance may well be shown by the behavior at three pressures, 12000 pounds, 18000 pounds, and 24000 pounds. For that reason cards taken at these three pressures only are inserted in this thesis.

12000 pounds.

This is a pressure which represents the maximum used in full service applications with the ordinary equipment. This pressure is not so high as to cause excessive heating or even any great wearing of the shoe, although the face is heated to incandescence in many cases. This takes place most often when the shoe is not in contact with the wheel over the entire face.

During some of the tests the action of the shoe was observed closely and it was noted that during almost the entire stop some parts of the shoe were bearing a much higher pressure than others as shown by the unequal heating.

In almost every case the shoe bore first on the ends. As the shoe became heated there was a tendency for it to flatten out and the heated section moved toward the center of the shoe so that in some cases shortly after the application had been made the ends were not in contact with the wheel.

From this point the action was by no means regular. In some cases the whole shoe bore on the wheel, at other times the area of maximum pressure moved back and forth over the entire surface of the shoe. It is probable that this warping of the shoe and the decrease of bearing area accompanying it account for the irregularities in the results of tests conducted under apparantly identical conditions.

By reference to the brake shoe machine card it will be seen that the coefficient of friction after the initial drop remains practically constant until near the end of the stop. This is a very desirable feature in a brake shoe as it makes it possible to use a high pressure throughout the stop without danger of sliding wheels.

18000 pounds.

In the tests at 18000 pounds shoe pressure the heating of the shoe was much more apparent. Sparks were thrown off from the shoe and in some cases a tongue of flame several inches long was produced just before the stop. The shoe did not, however, show excessive breakage even at this pressure.

24000 pounds.

When the pressure was increased to 24000 pounds the heat was not conducted away from the face of the shoe as rapidly as it was generated and the molten iron was torn away from the wheel and issued in a stream of sparks and flame. At the end of the test the shoe was red hot even on the back.

It was found that when the weights for the 24000 pound tests were allowed to drop from the trip the vibration at the start was excessive and for that reason the weights were applied by releasing the air from the cylinder below the weight lever.

Test With Half Shoe at 12000 pounds.

Before the tests at 24000 pounds were made a pressure of 12000 pounds was tried on a shoe which had been cut away so that it bore on but half the face. While it might be expected that under these conditions the coefficient of friction would be the same as when 24000 pounds was applied to a whole shoe as a matter of fact a much higher coefficient was developed. The explanation of this is probably to be looked for in the very great amount of energy dissipated by the small mass of iron. In the 24000 pound tests the iron was probably torn from the toe of the shoe and as it was carried along by the wheel acted as a lubricant while with the half shoe the metal was carried away very quickly and the shoe and wheel were always in intimate contact.

Diamond-S. 18000 pounds.

The Diamond-S shoe shows a higher coefficient of friction at 18000 pounds than the cast iron shoe probably because of the higher temperature necessary to melt the steel inserts. The heating of the shoe seemed to be less but the cast iron was melted away so that the steel stood out from the face of the shoe after the application. Except for the more pronounced falling off of the coefficient at the start the retarding effect was practically constant throughout the stop.

24000 pounds.

The behavior of the shoe at 24000 pounds is peculiar as may be seen by referring to the brake shoe machine card. During the first half of the stop the coefficient was about normal but when the shoe had become heated it was abraded by the wheel very rapidly. A solid sheet of flame about two feet long streamed from the shoe and the coefficient of friction rose very markedly up to the stop.

If such high pressures were to be used on the shoe this increasing coefficient would be a serious disadvantage since a low retarding effect would be secured during the first part of the stop unless some such device as the high speed blow down were used.

Streeter Shoe. 18000 pounds.

The results obtained with the Streeter shoe at 18000 pounds were very much the same as with the other shoes. The mean coefficient obtained was higher than that of the plain cast iron shoe but somewhat lower than that of the Diamond-S. The shoe threw very little fire and did not wear away rapidly.

24000 pounds.

At the high pressure this shoe threw but few sparks but the effect of heating is apparent in the rise of the coefficient of friction toward the end of the stop. The mean coefficient in this case was less than that obtained with the plain cast iron shoe at this pressure. This is the only case where the coefficient for either of the composition shoes fell below that of the cast iron shoe.

Tests with Air.

The main object of the tests made with air was to determine whether there was any appreciable difference in the coefficient of friction obtained in this way and that found by the use of weights. It was also thought that there might be some differences in the action of the shoe under pressure secured by weights and by air which could be discovered by this means.

So far as could be ascertained the action is the same in both cases. The brake cylinder has an advantage over the weights in being free from vibration. This gives, in some cases, a line with less irregularities and makes it possible to investigate more satisfactorily the initial drop in the coefficient of friction.

General Results and Conclusions.

These tests show that the decrease in the mean coefficient of friction with an increase of pressure which has been observed at lower pressures continues up to 24000 pounds. In spite of this decrease, however, every increase in pressure results in shortening the stop. The only exception to this rule is found at 24000 pounds with the cast iron shoe and this is doubtless due to the fact that with the small number of tests made at this pressure a fair average was not secured.

The decreased efficiency of the brakes at high pressure is well illustrated by a comparison of the length of stops at 12000, 18000, and 24000 pounds. At 12000 pounds pressure the stop was made in 2751 feet. An increase of pressure to 18000 pounds or 50 per cent decreased the length of stop but 21.9 per cent, and an increase to 24000 pounds or 100 per cent decreased the length of stop 39.3 per cent.

In view of the low coefficients of friction obtained at these high pressures, the rapid destruction of brake shoes, and the difficulty in designing satisfactory foundation brake gear, it would seem that any increase in weight per wheel would make the adoption of the clasp brake almost imperative. There seems no reason, however, why emergency pressures as high as 24000 pounds should not be used with equipments such as the "L.N." and the "P.C." in which a much lower pressure is used in ordinary service stops.

TESTS OF CAST IRON SHOE.

Test No.	M.P.H.	Length of stop.	Mean coeff. of fric-tion.	$L\frac{80^2}{S^2}$ [1]
		12000 pounds pressure.		
A1	84.5	2962	10.10	2650
A3	82.5	2686	9.63	2530
A4	82.7	2876	10.20	2685
A5	83.5	2886	10.10	2655
A6	82.6	3148	9.21	2958
A7	83.5	3011	9.66	2764
A8	82.3	3168	9.11	2990
A9	82.8	3009	9.54	2813
A10	82.8	2942	9.89	2712
		MEAN	9.72	2751
		14000 pounds pressure.		
A11	82.2	2537	9.94	2408
A12	81.7	2687	9.28	2580
A13	82.1	2707	9.32	2570
A14	82.3	2727	9.28	2580
		MEAN	9.45	2534
		16000 pounds pressure.		
A15	83.0	2393	9.22	2229
A16	84.0	2734	8.29	2475
A17	82.0	2498	8.63	2381
A18	82.3	2512	8.67	2372
		MEAN	8.70	2364
		18000 pounds pressure.		
A22	82.5	2120	9.18	1996
A23	82.8	2275	8.62	2125
A24	83.0	2243	8.79	2085
A25	82.6	2332	8.39	2185
		MEAN	8.74	2148

[1]Equivalent stop from 80 M.P.H.

TESTS OF CAST IRON SHOE.- (Cont.).

Test No.	M.P.H.	Length of stop.	Mean coeff. of fric-tion.	$L\frac{80^2}{S^2}$
	20000 pounds pressure.			
A44	82.5	1842	7.80	1730
A45	82.5	2054	6.94	1930
A46	82.5	2180	6.01	2050
		MEAN	6.92	1903
	22000 pounds pressure.			
A47	82.5	1397	8.75	1315
A48	82.5	1952	6.86	1835
A49	82.5	1593	7.66	1495
A50	82.5	1878	6.20	1770
		MEAN	7.62	1604
	24000 pounds pressure.			
A51	82.5	1661	7.14	1560
A52	82.5	1894	6.40	1780
		MEAN	6.77	1670

HALF SHOE.

Test No.	M.P.H.	Length of stop.	Mean coeff. of friction.	$L\frac{80^2}{S^2}$
	12000 pounds pressure.			
A39	81.0	2460	10.93	2400
A40	82.5	2545	11.21	2405
		MEAN	11.07	2402

TESTS WITH DIAMOND-S. SHOE.

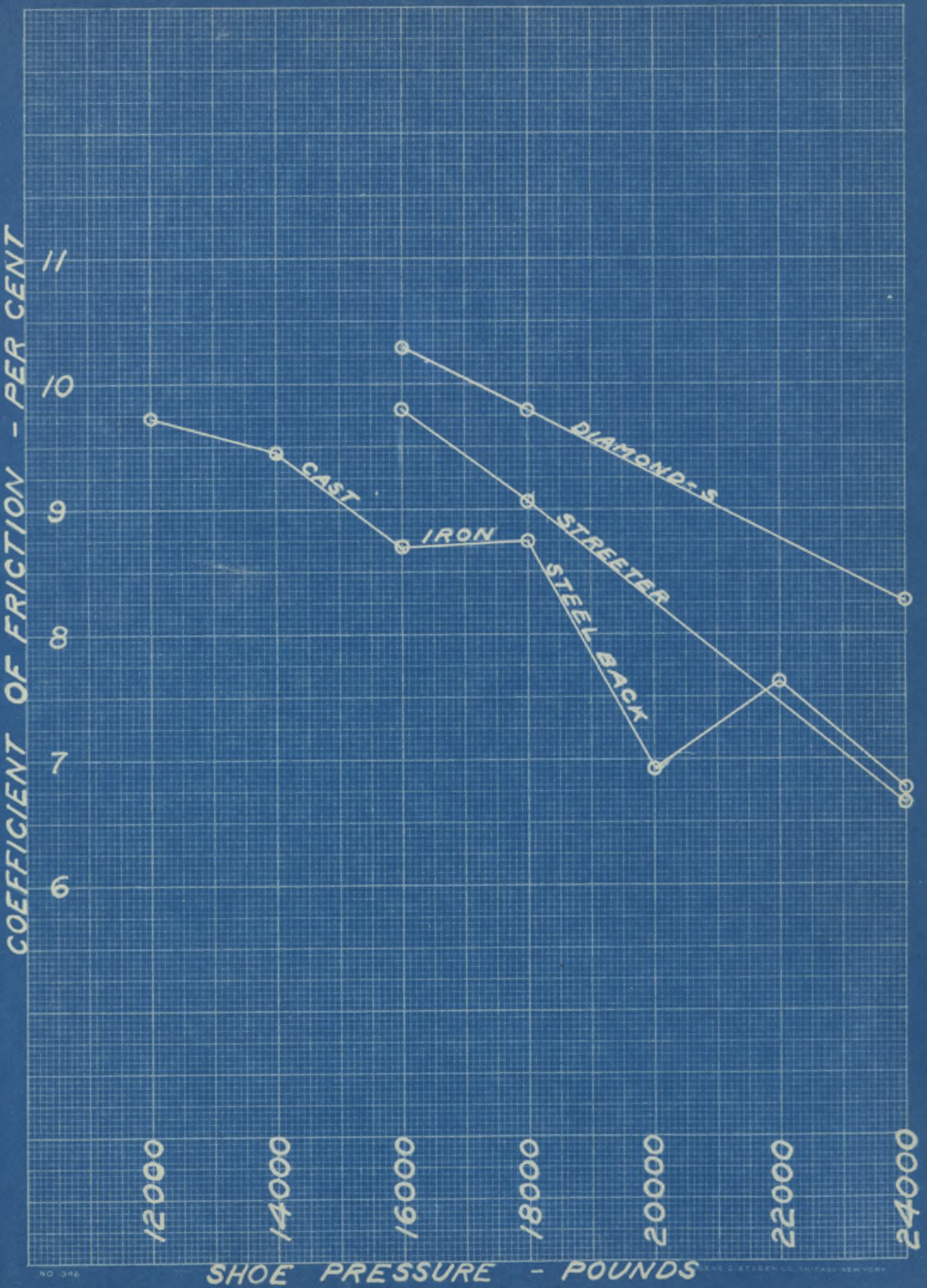
Test No.	M.P.H.	Length of stop.	Mean coeff. of friction.	$L\frac{80^2}{S^2}$
	16000 pounds pressure.			
B2	82.7	2168	10.06	2030
B3	83.1	2028	10.71	1870
B13	82.5	2129	10.09	2000
		MEAN	10.29	1967
	18000 pounds pressure.			
B1	82.7	1926	10.14	1800
B5	82.8	2202	9.09	2060
B10	82.5	1943	10.15	1820
		MEAN	9.79	1893
	24000 pounds pressure.			
B16	82.5	1293	9.20	1215
B17	82.5	1701	7.10	1600
B18	82.5	1387	8.50	1305
		MEAN	8.27	1373

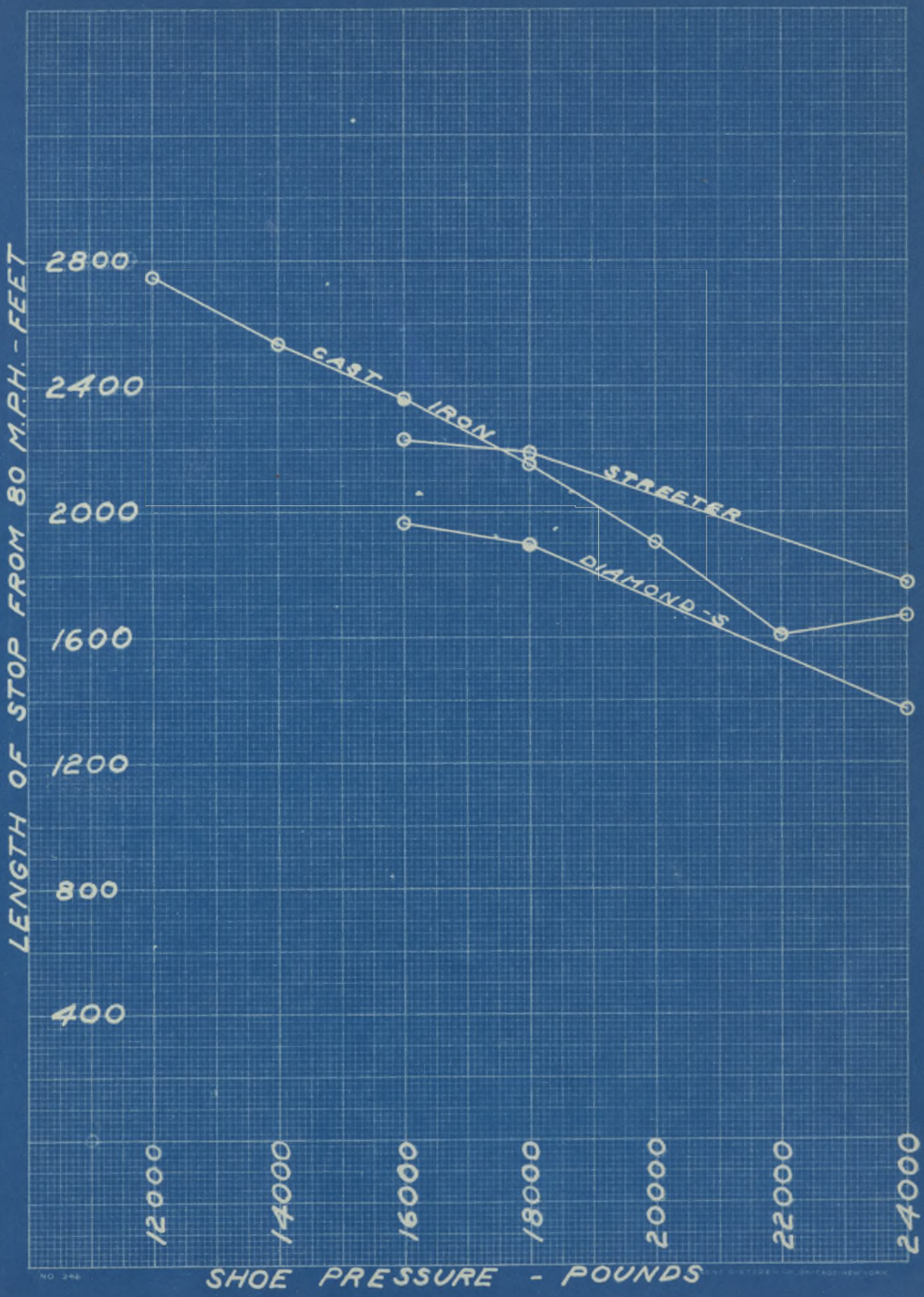
TESTS WITH STREETER SHOE.

Test No.	M.P.H.	Length of stop.	Mean coeff. of friction.	$L\frac{80^2}{S^2}$
	16000 pounds pressure.			
C4	82.5	2312	10.20	2175
C5	82.5	2430	9.41	2285
		MEAN	9.80	2230
	18000 pounds pressure.			
C1	82.9	2342	8.97	2180
C2	82.0	2425	8.72	2310
C3	82.8	2215	9.49	2070
		MEAN	9.06	2187
	24000 pounds pressure.			
C13	82.5	1885	6.65	1770

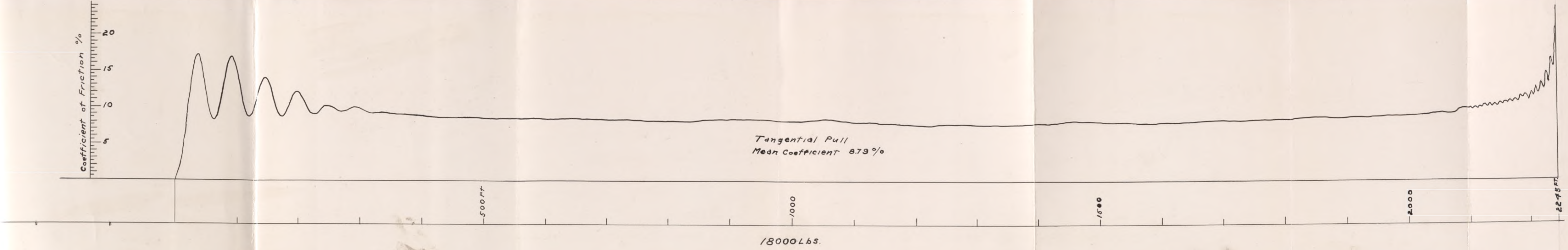
TESTS WITH AIR.

Test No.	Press.	M.P.H.	Length of stop.	Mean coeff. of friction.
	Cast Iron Shoe.			
A32	14800	83.9	2114	10.84
A34	18640	82.5	1999	9.35
	Diamond-S Shoe.			
B8	15170	82.5	2357	9.55
B7	15470	82.5	2186	10.44
B6	18910	82.5	1710	10.52
	Streeter Shoe.			
C7	17750	83.0	2125	9.71
C8	18870	82.5	2253	8.47


COEFFICIENT OF FRICTION - PER CENT
11
10
9
8
7
6
DIAMOND-S
CAST
IRON
STREETER
STEEL BACK
12000
14000
16000
18000
20000
22000
24000
SHOE PRESSURE - POUNDS


LENGTH OF STOP FROM 80 M.P.H. - FEET
2800
2400
2000
1600
1200
800
400
CAST IRON
STREETER
DIAMOND-S
12000
14000
16000
18000
20000
22000
24000
SHOE PRESSURE - POUNDS


Coefficient of Friction %
20
15
10
5
Tangential Pull
Mean Coefficient 9.66 %
500 Ft.
1000
1500
2000
2500
3011 Ft.
12000 Lbs.


Coefficient of Friction %
20
15
10
5
Tangential Pull
Mean Coefficient 8.79 %
500 Ft
1000
1500
2000
2245 Ft
18000 Lbs.

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BRAKE SHOE TESTS.

TEST NUMBER A 32 DATE ______ 191__

SHOE NAME Cast Iron SB NUMBER ______

TOTAL WEIGHT Air SHOE PRESSURE 1" = 10 000 lbs.

INITIAL SPEED, M. P. H. 84. WEARING SPEED ______

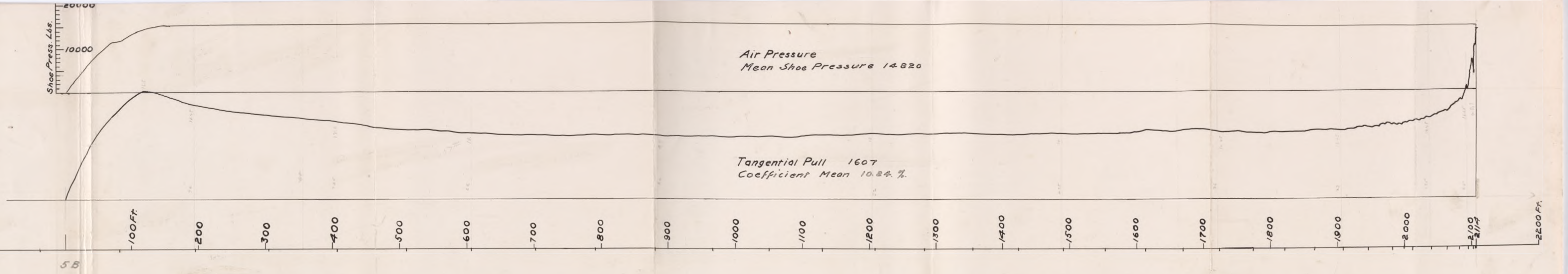
REVOLUTION COUNTER, BEFORE ______ AFTER ______

COEFF. ______ SEC. AFTER APPLICATION ______

COEFF. ______ SEC. BEFORE RELEASE ______

COEFF. MEAN, 10.84

CORRECT ______



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BRAKE SHOE TESTS.

TEST NUMBER 2037 DATE 4/24 1911

SHOE NAME Cast Iron SB NUMBER 7

TOTAL WEIGHT ______ SHOE PRESSURE 24000#

INITIAL SPEED, M. P. H. 80 WEARING SPEED ______

Air Release

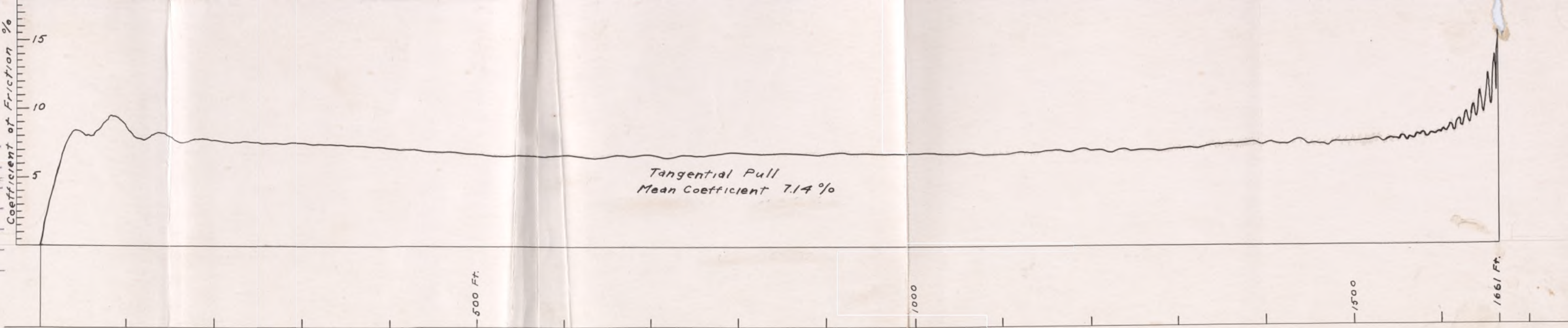
REVOLUTION COUNTER, BEFORE ______ AFTER ______

COEFF. ______ SEC. AFTER APPLICATION ______

COEFF. ______ SEC. BEFORE RELEASE ______

COEFF. MEAN, 7.14

CORRECT ______



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BRAKE SHOE TESTS.

...MBER ______ DATE ______ 191__

...ME Diamond S NUMBER 5220

...EIGHT ______ SHOE PRESSURE 18000

... SPEED, M. P. H. 83.4 WEARING SPEED ______

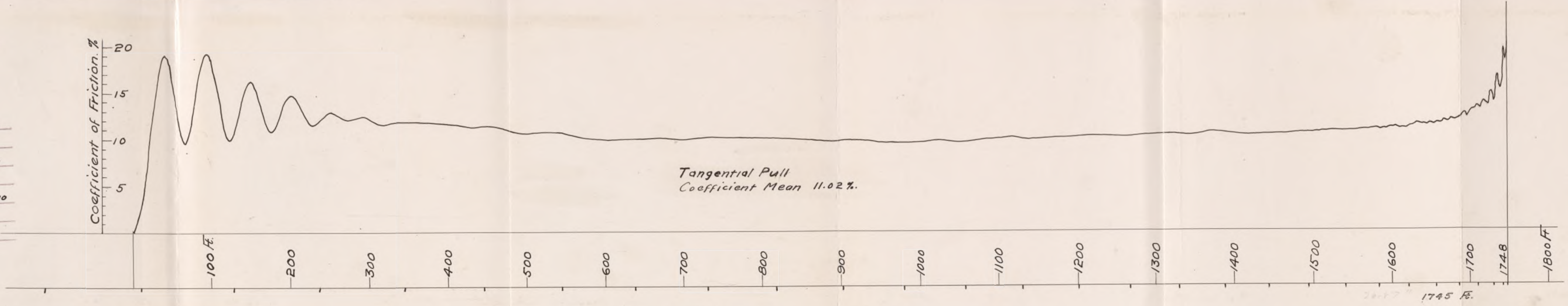
...TION COUNTER, BEFORE 73102 AFTER 73310

______ SEC. AFTER APPLICATION ______

______ SEC. BEFORE RELEASE ______

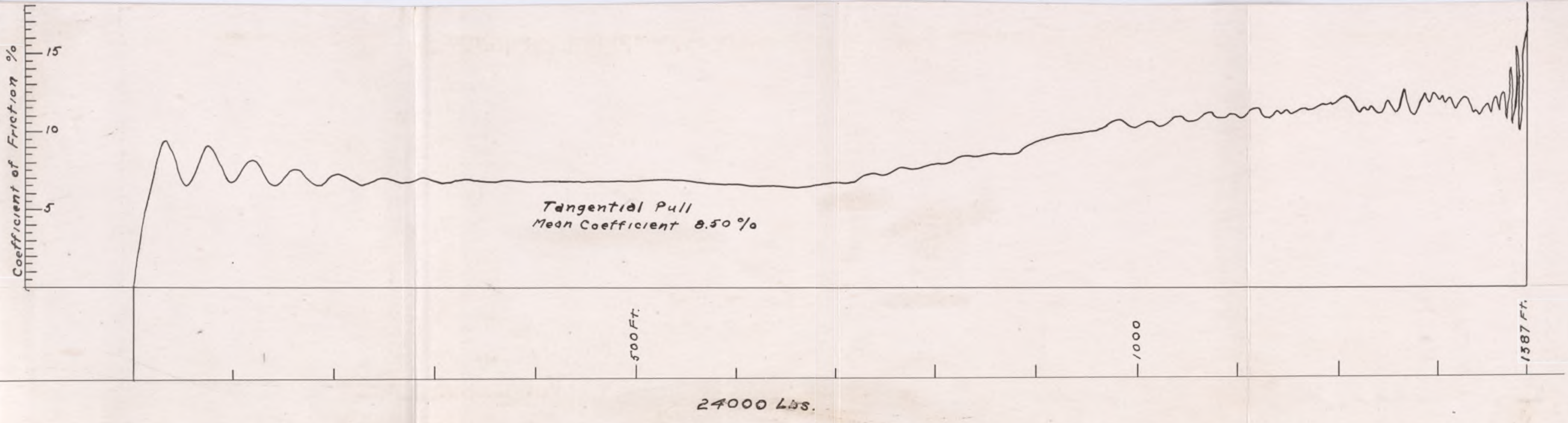
... MEAN, 11.02

...CT ______

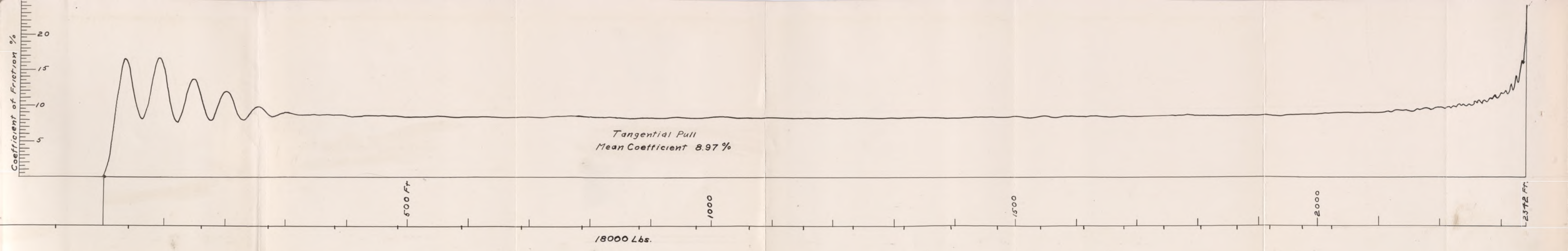


4 A

18000 Lbs.



Coefficient of Friction %
15
10
5
Tangential Pull
Mean Coefficient 8.50 %
500 Ft.
1000
1587 Ft.
24000 Lbs.



Coefficient of Friction %
20
15
10
5
Tangential Pull
Mean Coefficient 8.97 %
500 Ft.
1000
1500
2000
2342 Ft.
18000 Lbs.

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BRAKE SHOE TESTS.

TEST NUMBER 3 C9 DATE ______ 191__

SHOE NAME Streeter NUMBER 30288

TOTAL WEIGHT Air SHOE PRESSURE 1" = 10 000 lbs.

INITIAL SPEED, M. P. H. 81.7 WEARING SPEED ______

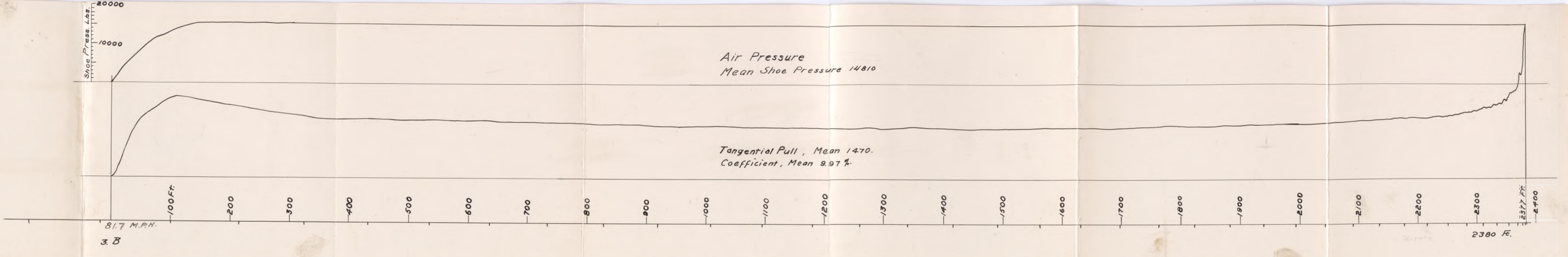
REVOLUTION COUNTER, BEFORE ______ AFTER ______

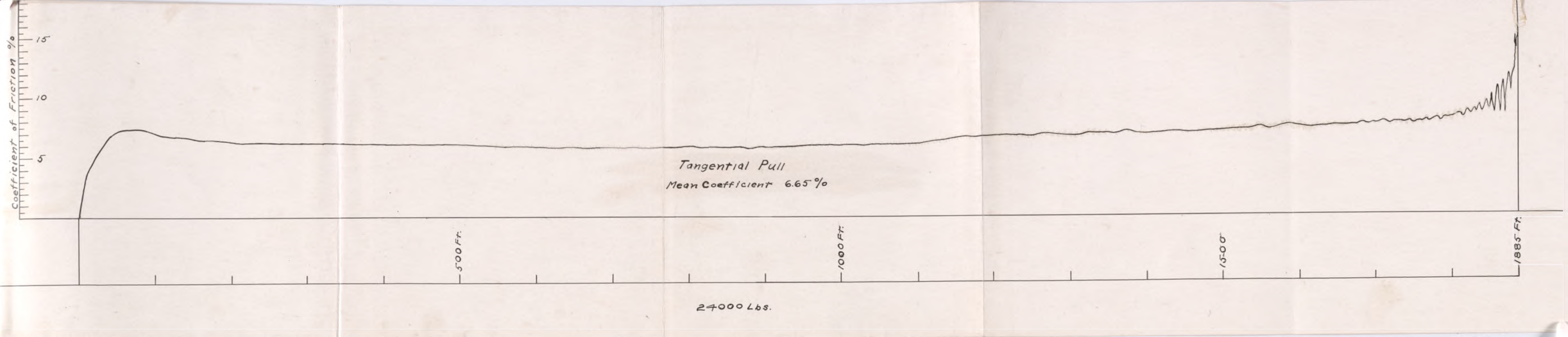
COEFF. ______ SEC. AFTER APPLICATION ______

COEFF. ______ SEC. BEFORE RELEASE ______

COEFF. MEAN, ______

CORRECT ______





Coefficient of Friction %
15
10
5
Tangential Pull
Mean Coefficient 6.65 %
500 Ft.
1000 Ft.
1500
1885 Ft.
24000 Lbs.